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NOTE

Environment

Cover crop effects on soil carbon dioxide emissions in a semiarid cropping system

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Abstract

Cover crops improve soil health and environmental quality by enhancing soil organic carbon (SOC) sequestration and nutrient cycling in agroecosystems. This study evaluated the effect of cover crops on soil CO_2–C emissions, temperature, and water content during cover crop growth from April to October, 2017 and 2018. Treatments included fallow, pea (*Pisum sativum* L.), oat (*Avena sativa* L.), canola (*Brassica napus* L.), pea–oat (POmix), pea–canola (PCmix), pea–oat–canola (POCmix), and POC–hairy vetch (*Vicia villosa* L.)–forage radish (*Raphanus sativus* L.)–barley (*Hordeum vulgare* L.) (six species mixture; SSmix). The CO_2–C emissions were monitored weekly from April to October each year using a portable infrared-gas analyzer. Seasonal changes in CO_2–C emissions varied with cover crops and peaked as soil temperature and water content following precipitation events. Average CO_2–C emissions across sampling dates was 46–70% greater under pea than under fallow, canola, and POmix in 2017, but not different among cover crops in 2018. Although the emissions were higher than fallow, canola and POmix plots had lower CO_2–C emissions than other cover crops. Pea as sole cover crop or in mixtures (PCmix, POCmix, SSmix) increased CO_2–C emissions and microbial activity whereas canola and POmix mixture reduced the emissions during the period with higher precipitation.

1 | INTRODUCTION

The CO_2 emission is the main pathway of soil C loss to the atmosphere, and it serves as an indicator of soil biological health (Parkin & Kaspar, 2003). The soil CO_2 production mostly results from plant root respiration and heterotrophic respiration during soil organic matter (SOM) decomposition (Liu et al., 2016). Soil temperature and water content, which are influenced by air temperature and precipitation, vegetation cover, and soil management, play a critical role in soil CO_2 emissions (Bao et al., 2016). Increased soil temperature and moisture typically increases soil microbial activity and nutrient release, thereby elevating soil CO_2 emissions. Management practices that increase precipitation storage efficiency and decrease soil temperature by providing surface cover have the potential to increase soil biological activity that leads to improved SOM sequestration (Liu et al., 2016). Improved knowledge of the role of enhanced soil cover on soil temperature, soil moisture, and CO_2 emissions through diverse cover cropping practices could help in designing sustainable and ecologically sound cropping systems.

Abbreviations: EGM, environmental gas monitoring; PCmix, pea–canola mixture; POCmix, pea–oat–canola mixture; POmix, pea–oat mixture; PVC, polyvinylchloride; SHP, southern High Plains; SOC, soil organic carbon; SOM, soil organic matter; SRC, soil respiration chamber; SSmix, six species mixture: pea–oat–canola–hairy vetch–forage radish–barley mixture.

In recent years, cover cropping is increasingly considered in semiarid regions to increase SOM sequestration and improve soil health because of their biomass C contribution, soil temperature moderation, moisture conservation, soil aggregation, and aggregate stability (Blanco-Canqui, Holman, Schlegel, Tatarko, & Shaver, 2013; Ghimire, Ghimire, Mesbah., Sainju, & Idowu, 2019; Thapa, Ghimire, Duval, & Marsalis, 2019). Cover crops can enhance nutrient cycling and water productivity and thereby sustain crop production compared with fields without cover crops (Holman et al., 2012; Reese et al., 2014). Cover crops reduce soil erosion by providing a surface coverage (Rhoton, Shipitalo, & Lindbo, 2002). Legume cover crops fix N from the atmosphere and supply to succeeding crops, thereby reducing N fertilization rates and enhancing crop yields (Dabney, Delgado, & Reeves, 2001; Quemada & Cabrera, 1995).

Increased soil biological activity due to cover cropping also elevate total soil respiration because of the root and associated heterotrophic respiration. Studies on cover cropping and role of enhanced soil cover on soil temperature, moisture, and their effects on soil CO_2–C emissions could improve agricultural sustainability and environmental quality. It could be particularly beneficial to the semiarid cropping systems such as in the southern High Plains (SHP) region where crop production is challenged by low soil fertility, limited water availability for irrigated crop production, and high seasonal and inter-annual variability in temperature and precipitation. The SHP region relies on Ogallala Aquifer for irrigated crop production and water level in the aquifer is declining leading to rapid transitioning of cropping practices (Cano et al., 2018; Ghimire et al., 2019). Studies are limited on the effect of cover crops and their mixtures on soil CO_2–C emissions, and their relationship with soil moisture and temperature. The data is lacking from a hot, dry, semiarid environment of the SHP region transitioning from irrigated to limited irrigation or dryland production.

The aim of this study was to examine the effect of cover crops on soil CO_2 emissions (measured as CO_2-C) in limited irrigation cropping systems in the semiarid environment of the SHP. We hypothesized that legume cover crops enhance CO_2–C emissions more rapidly than nonlegumes and the mixture of legume and nonlegume cover crops.

Core Ideas

- Cover crop effects on soil CO_2–C emissions were evaluated in 2017 and 2018.
- The CO_2–C emissions were higher with cover crops than with fallow.
- Peas and their mixture with other cover crops increased soil biological activity.
- Soil temperature and moisture interact to influence soil CO_2–C emissions.

2 | MATERIALS AND METHODS

The study was conducted at the New Mexico State University, Agricultural Science Center, Clovis, NM (34°35′ N, 103°12′ W; elevation 1,348 m) during 2017 and 2018. The site has a semiarid climate, with 470 mm mean annual precipitation and 15 °C average air temperature. Daily precipitation during the study period is presented in Figure 1. The soil is Olton clay loam (fine, mixed, superactive, thermic Aridic Paleustolls) with sand, silt, and clay contents of 437, 215, and 348 g kg^{-1}, respectively, soil pH 8.1, bulk density 1.2 Mg m^{-3}, and SOM 14.5 g kg^{-1}.

The study was conducted in a randomized complete block design with eight treatments and three replications. Treatments consisted of fallow (no cover crop), oat, pea, canola, pea–oat mixture (POmix), pea–canola mixture (PCmix), pea–oat–canola mixture (POCmix), and six species mixture of pea–oat–canola–hairy vetch–forage radish–barley (SSmix). Cover crops were planted in the last week of February using a no-till drill (Great Plains 3P600) and terminated by applying herbicides in the third week of May each year. The monoculture seeding rate for oat, pea, canola, barley, hairy vetch, and forage radish was 44.8, 22.4, 4.5, 44.8, 11.2, and 4.5 kg ha^{-1}, respectively. The seeding rates were 50, 33, and 16.5% of the monoculture rates for two species, three species, and six species mixtures, respectively. The individual plot size was 12 by 18 m. Before cover crop planting, the field was fallowed following sorghum harvest in October of the previous year, and cover crop residues were maintained after cover crop termination until winter wheat planting in October in both years. Crop rotation and management details are described in Mesbah, Nilahyane, Ghimire, Beck, and Ghimire (2019). Cover crops did not receive irrigation or fertilizers. Winter wheat was planted in October 2017 and 2018. At planting, winter wheat received 70 kg N ha^{-1} and 12 kg S ha^{-1}. Winter wheat received limited irrigation (~175 and ~250 mm in 2017 and 2018, respectively) at critical growth stages. Sorghum before cover cropping received 97 kg N ha^{-1} and 15 kg S ha^{-1} each year. Cover crops and fallow field did not receive any irrigation during CO_2–C measurements period.

Soil CO_2–C emissions were measured weekly during April (early growth stage of the cover crops) through first week of October (before wheat planting) each year using a soil respiration chamber (SRC-2) connected to an Environmental Gas Monitoring System (EGM-5; PP Systems). Before measurements, 10 cm deep by 10 cm i.d. polyvinylchloride (PVC) rings were installed to a depth of 8 cm between cover crop rows (row spacing 25 cm for cover crops and 76 cm for

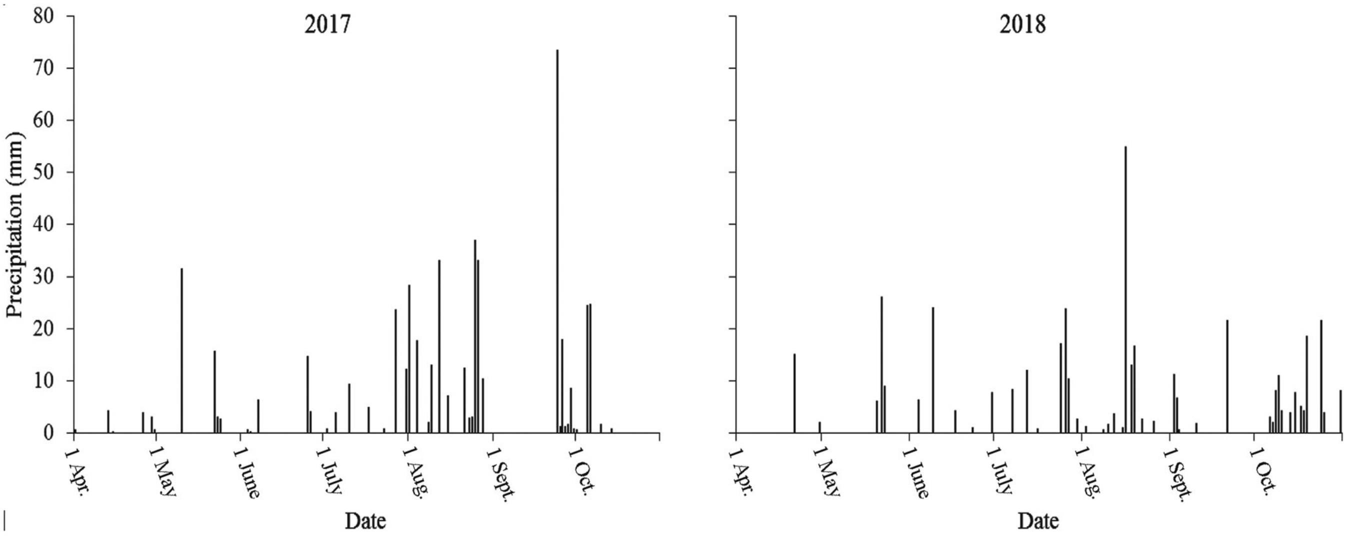

FIGURE 1 Daily precipitation during 2017 and 2018 soil CO_2–C emissions measurements

previous year's sorghum) at the center of each plot. The rings were removed during field operations and reinstalled immediately after each field operation. Any living plant inside the chamber was hand clipped and removed before each sampling to avoid CO_2–C contributions from aboveground plant parts. However, root and heterotrophic respiration could not be separated in this study. Therefore, CO_2–C measured included emission from all soil processes. During each measurement, a SRC-2 chamber was placed into a PVC ring for 5 min, and gas accumulated in the chamber headspace was measured directly into the EGM-5 analyzer connected to the chamber. Gas emissions were calculated by using a linear procedure of flux calculation using a formula described in Thapa et al. (2019). Gas samples were collected between 0900 and 1100 h during each observation to reduce variability in CO_2–C flux due to diurnal fluctuations in temperature. Soil temperature and water content at the 0- to 5-cm depth were measured using probes (Stevens Water Monitoring Systems) attached to the EGM-5 analyzer. Daily precipitation and air temperature were recorded from a weather station near the study site.

Data were analyzed by using the MIXED procedure of SAS (SAS Institute) in which cover crop was considered the fixed effect, measurement date was repeated measure factor, and replication was the random effect. Means were separated using the LSMEANS test ($p \leq .05$). Orthogonal contrasts were used to determine the effect of cover crop vs. fallow on CO_2–C emissions and soil parameters. Multiple regression analysis was performed to assess the relationship between soil temperature, water content, and CO_2–C emission. The combined soil temperature–moisture coefficient was calculated by using multiple regression function in SigmaPlot 14 (Systat Software). The combined coefficient was used to graph the result, but original equation is presented to show the relative effects of soil moisture and temperature on CO_2–C emissions.

3 | RESULTS

Total precipitation received during the study period (April–October) accounted for 70% of the annual precipitation (Figure 1). In 2017, 503 mm of precipitation was received during this period compared with 417 mm in 2018. Soil temperature varied among cover crops and measurement dates (Table 1). Soil temperature decreased in May 2017 following precipitation, increased from June to August, and then declined (Figure 2). In 2018, soil temperature increased from May to August and decreased after that. Soil temperature was higher in late May, lower in June to August, and higher in September with oat than with other cover crops.

Soil water content increased immediately following precipitation events in both years (Figure 2). Soil water content was higher under fallow than cover crops from April to August 2017. In 2018, soil water content was higher under oat than other cover crops from May to July, but lower in August. Averaged across measurement dates, water content was higher with fallow than cover crops in 2017 (Table 1).

Soil CO_2–C emissions differed among measurement dates and cover crops, with a significant cover crop × measurement date interaction in both years, except for cover crop in 2018 (Table 1). In 2017, CO_2–C emissions were greater with pea and PC than other cover crops in June and August to October (Figure 2). The flux was lower with fallow for most of the measurement dates. In 2018, CO_2–C emissions were greater with POCmix in June and with fallow, PC, and SSmix in July and August than other cover crops. Lower emissions occurred with pea in May and August and with oat in July. Averaged across measurement dates, the CO_2–C emissions were greater with pea than fallow, canola, and POmix in 2017, but cover crops did not affect gas emissions in 2018 (Table 1). The orthogonal contrasts showed that mono- and polyculture cover crops had greater CO_2–C emission than fallow in

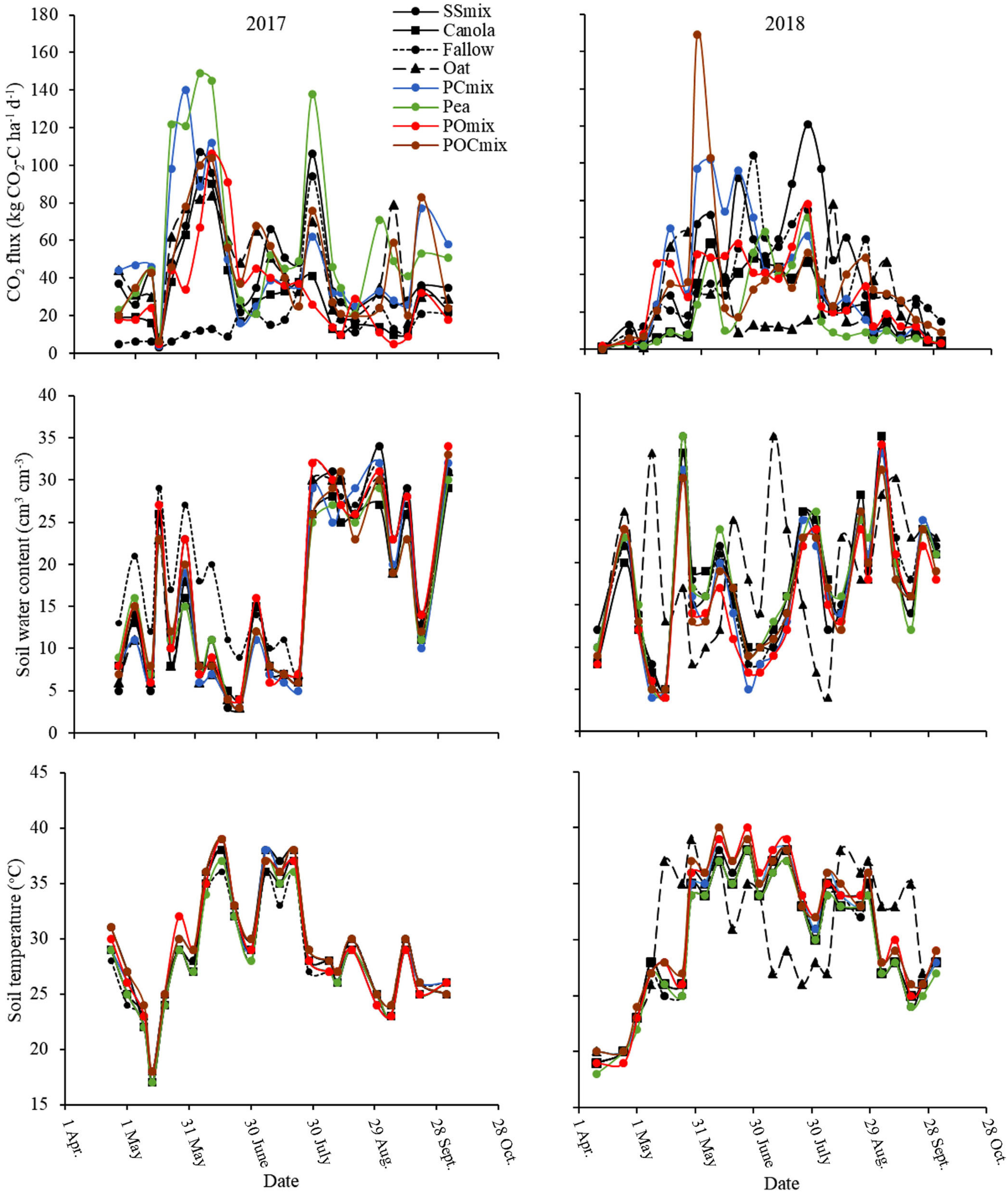

FIGURE 2 Effect of cover crops on soil CO_2–C emissions, soil water content, and soil temperature at the top 5-cm soil depth during 2017 and 2018. POmix, pea–oat mixture; PCmix, pea–canola mixture; POCmix, pea–oat–canola mixture; SSmix, six species mixture: pea–oat–canola–hairy vetch–forage radish–barley. Pea, *Pisum sativum* L.; oat, *Avena sativa* L.; canola, *Brassica napus* L.; hairy vetch, *Vicia villosa* L.; radish, *Raphanus sativus* L.; barley, *Hordeum vulgare* L.

TABLE 1 Means of soil temperature, soil water content, and daily CO_2–C emissions during 2017 and 2018 at Clovis, NM

	Soil temperature (T_S)		Soil water content (M)		CO_2–C emission	
	2017	2018	2017	2018	2017	2018
Cover crop	°C		cm^3 cm^{-3}		kg CO_2–C ha^{-1}	
Fallow	28.1	30.3	20.0[a]	17.8	18.3d	35.2
Canola	28.5	30.5	15.4b	18.1	30.6cd	22.7
Oat	28.9	31.1	15.9b	18.8	45.0abc	22.6
Pea	28.2	30.0	15.6b	18.0	60.9a	18.9
PCmix	29.0	31.2	15.6b	16.7	50.1ab	36.1
POmix	29.0	31.4	17.1b	16.1	32.9bc	30.1
POCmix	29.5	31.5	15.9b	16.8	46.5abc	35.4
SSmix	29.3	30.8	16.9b	17.6	46.2abc	40.9
	Significance					
Date	***	***	***	***	***	***
Treatment	ns[b]	ns	**	ns	**	ns
Date × Treatment	ns	ns	***	ns	**	***
	Contrasts					
Monoculture (canola, oat, pea) vs. fallow	0.4	0.2	−4.4***	0.5	27.2**	−13.8
2 species (PCmix, POmix) vs. fallow	0.9	1.1	−3.7***	−1.5	23.2*	−2.1
All vs. fallow	0.7	0.3	−4.1***	0.3	26.3**	−5.6

[a]Means followed by different lowercase letters in a column are significantly different (p = .05).
[b]ns, not significant.
Note. PCmix, pea–canola mixture, POmix, pea–oat mixture, POCmix, pea–oat–canola mixture, SSmix, six species mixture: pea–oat–canola–hairy vetch–forage radish–barley. Pea, *Pisum sativum* L.; oat, *Avena sativa* L.; canola, *Brassica napus* L.; hairy vetch, *Vicia villosa* L.; radish, *Raphanus sativus* L.; barley, *Hordeum vulgare* L.
*Significance at $p \leq .05$.
**Significance at $p \leq .01$.
***Significance at $p \leq .001$.

2017 but such a difference was not observed in mono- vs. polyculture comparison.

Multiple regression analysis revealed a significant relationship of soil CO_2–C emissions with soil temperature and soil moisture (Figure 3). Daily soil CO_2–C emissions increased by 0.96 and 2.72 kg ha^{-1} per unit increase in temperature in 2017 and 2018, respectively, whereas daily CO_2–C emissions decrease by 0.63 and 0.44 kg ha^{-1} in 2017 and 2018 with each unit increase in soil water content.

4 | DISCUSSION

We observed lower CO_2–C emission from fallow plots than cover crop plots in most measurement dates in 2017 (Figure 2), likely due to the absence of plants, which affected root respiration. Root respiration during cover cropping period was null in fallow plots. Studies show that plant root respiration contributes from 10 to 90% of the total soil CO_2–C flux (Hanson, Edwards, Garten, & Andrews, 2000; Rochette, Flanagan, & Gregorich, 1999). Greater CO_2–C emissions with pea and PC from June to October 2017 was probably a result of rapid turnover of above- and belowground biomass of pea residue. Residues of legumes, such as pea, have lower C/N ratios, resulting in rapid decomposition and releasing more CO_2–C than non-legumes (Kuo, Sainju, & Jellum, 1997; Sainju, Jabro, & Stevens, 2008). As CO_2–C emissions and nutrient release, such as N, during decomposition of cover crop residue in the soil are related, quick nutrient release indicated by high CO_2–C emissions from pea residue following cover crop termination in May will be less available to winter wheat planted in October due to a longer lag period. In contrast, lower CO_2–C emissions from nonlegume than pea during summer indicates slow nutrient release that would probably available during the winter wheat growth.

Our objectives were to improve soil health and reduce soil C loss as CO_2–C emissions from cover crop residue and also synchronize N release from the residue with winter wheat N demand. With this concept, nonlegume or mixed cover crop would be more ideal to accomplish these objectives. However, we observed high seasonal and interannual variations in CO_2–C emissions, which were related to fluctuations in soil temperature and water content. Seasonal and interannual variation in CO_2–C emissions is often related with changes in

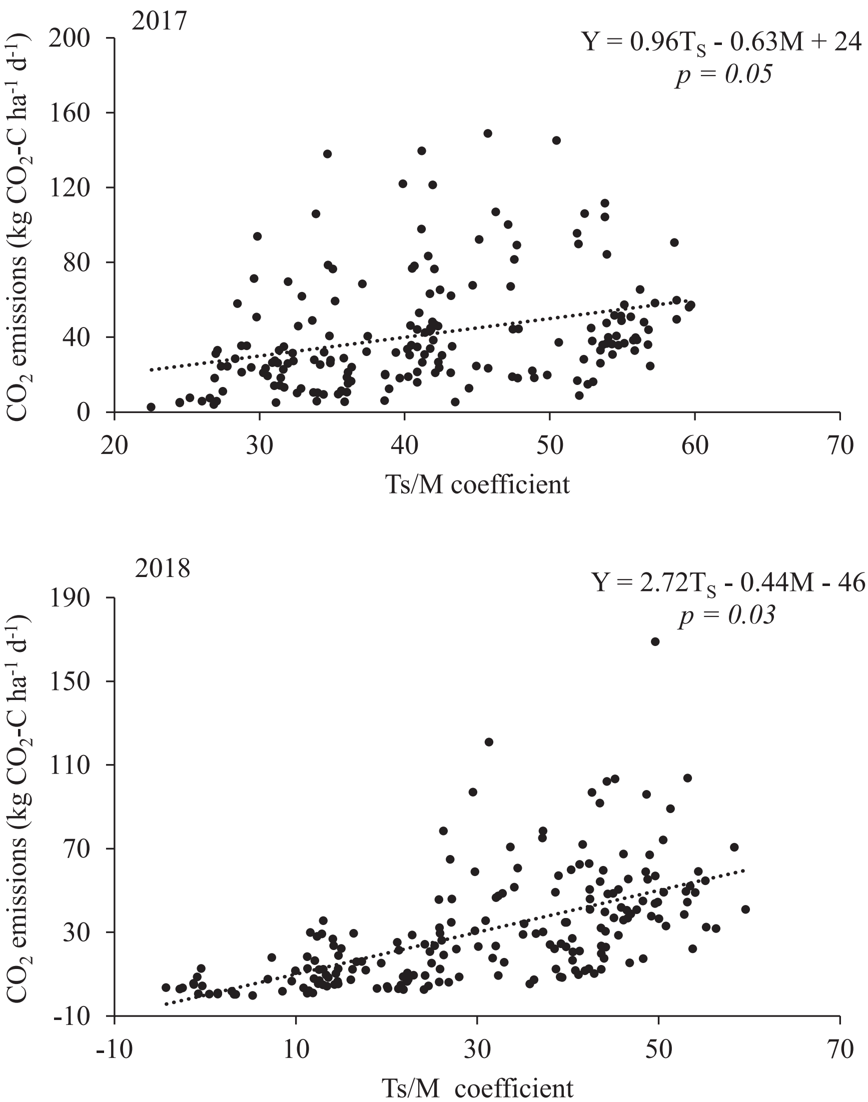

FIGURE 3 Relationship between soil temperature (T_S), soil water content (M), and soil CO_2–C emissions during 2017 and 2018

soil temperature, moisture, and nutrient dynamics (Suseela, Conant, Wallenstein, & Dukes, 2012). The CO_2–C emissions were higher from June to August 2018 than other dates, likely due to increased soil water content that enhanced microbial activity and rapid mineralization of crop residues. In 2017, July was relatively dry, leading to low CO_2–C fluxes across all treatments. The fluxes increased again in August after rain events, suggesting precipitation as the primary driver of CO_2–C emissions.

Variation in CO_2–C emissions among cover crops was related to root respiration during cover crop phase, and the quality and quantity of cover crop residue returned to the soil that affected the mineralization of residue after cover crop termination. Mesbah et al. (2019) from the same experiment reported that cover crop biomass returned to the soil in 2017 was greater with oat (2,873 kg ha^{-1}), POmix (3,077 kg ha^{-1}), POCmix (2,816 kg ha^{-1}), and SSmix (2,482 kg ha^{-1}) than pea (1,445 kg ha^{-1}) and canola (1,847 kg ha^{-1}). Pea matures early and uses less soil water than cereals leaving more soil water available for the following crops or fallow period (Lenssen, Johnson, & Carlson, 2007), which may stimulate microbial activity and greater CO_2–C fluxes. Canola and POmix appears to have lower CO_2–C emissions than other cover crops. Ghimire et al. (2019) from a 2-yr study at the same site reported a higher SOC storage under oat and its mixture with other species as cover crops.

Higher CO_2–C fluxes in 2017 than 2018 were related to more considerable variation in precipitation in 2017 than 2018, which may have affected soil moisture, temperature, and CO_2–C emissions. The multiple regression results also indicated that changes in soil temperature and soil water content affect the soil CO_2–C flux regardless of cover crop type. Dry soils often have higher temperature than wet soils and increase CO_2–C emissions. Increased soil water content in dry soils up to field capacity increases microbial activity and root respiration, further increasing CO_2–C flux.

However, lack of statistical significance among cover crop treatments despite a large difference in average fluxes in 2018 was due to high coefficient of variation in CO_2–C emissions and high seasonal fluctuation in temperature and soil water content. The coefficient of variation of CO_2–C flux was >100% in 2018, which was considerably greater than 60% observed in 2017. This indicates that CO_2–C flux needs to be measured either with increased number of replications of treatments or measured at several places within a plot to reduce the spatial heterogeneity. Temporal heterogeneity of CO_2–C flux, however, will be less likely to be reduced due to dependence of the flux with soil temperature and water content that are related to climatic condition of the region. Reduced CO_2–C emissions with POmix compared with other cover crops in 2017 and 2018 suggests that a combination of pea and oat cover crops might reduce CO_2–C emissions while also helping to release nutrients during winter wheat growth due to slower decomposition of the cover crop residue.

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